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Role of Innovation Parks in Driving Digital Advances and Promoting Energy Efficiency

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Abstract

The impact of innovation parks on the development of digital transformation and energy savings of modern enterprises lies in the effectiveness of technology parks in stimulating economic development and technological progress, meeting the requirements of sustainable development through the support of innovation, green technologies, and entrepreneurship in the context of digitalisation. This article aims to study the critical aspects of the functioning and development of innovation parks in the context of accelerating digital transformation and developing new energy-saving methods. The study employed extensive literature analysis, systematisation, and generalisation to substantiate the role and critical aspects of park innovation development in the context of digital transformation and energy saving. To analyse the current state of development of innovation parks, the article uses an expert survey, descriptive statistics, and classification of scores. This was followed by correlation analysis, and calculation of weighted averages to identify key relationships. An integral indicator was used to evaluate the overall development efficiency of innovation parks. Two groups were selected as experts for the study: residents and employees of LvivTech.City (26 people) and UNIT.City Kharkiv (13 people), which are the largest innovation parks in Ukraine. The results revealed that the overall efficiency level of innovation park development is high relative to the total set of indicators (Ef Group 1 = 10.77; Ef Group 2 = 10.42). At the same time, the relationship between the effectiveness of innovation parks and the obstacles to their development, although statistically significant, has a low positive correlation ($r = 0.240$ at $p < 0.05$). Thus, the existing risks do not significantly impact the overall efficiency level of innovation parks. The study found that innovation parks, as catalysts for digital transformation and energy savings, provide a platform for integrating advanced technologies, guide research, and implement strategies for introducing energy-saving technologies and environmental initiatives, ensuring their competitiveness and sustainable development.

Keywords

Innovative entrepreneurship; Innovation parks; Digital transformation; Energy-saving technologies; Competitiveness; Digitalisation

Introduction

The development of innovation parks is an essential factor in economic growth and technological progress at both the macro and micro levels, given their ability to cover the entire innovation cycle. In addition, AURP (2024) reports a large number of research parks and innovation districts at modern North American universities, despite the need for additional funding (88%), have increased the availability of programmes in many areas, such as incubator space (94%) Networking (95%), and entrepreneurial programming (93%), which creates the preconditions for the intensive development of the innovation ecosystem, support for start-ups, and stimulation of economic growth through new technologies, including green and energy-efficient ones, and entrepreneurship. In digitalisation, the development of technology parks is mainly related to achieving sustainable development goals, including ensuring stability and economic growth, social responsibility, innovation and environmental friendliness of the business sector and the state (Krysovatyy, 2024). In this regard, the relevance of this study is due to the systematic growth of interest in the innovative prospects of science and technology parks in the context of the digitalisation of the economy and energy efficiency issues. The dynamics shown in figure 1 demonstrate the number of Google Trends searches worldwide over the past five years in digitalisation and energy saving in innovation parks.

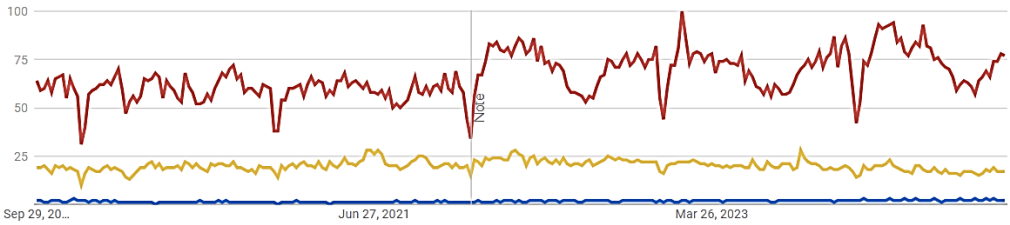

Figure 1: Number of Google Searches for Digitalisation and Energy Saving in Innovation Parks showing Search interest in energy efficiency (Red); Search interest in digitalisation (Yellow); and Search interest in innovation parks (Blue) (*Source:* Google Trends, 2024)

In terms of regions, the most significant interest in developing innovation parks is observed in the countries of Southern Africa (Eswatini, Namibia), the Middle East (Iran, Qatar) and, although with less intensity, Asia (Hong Kong, China, Pakistan). Instead, the issue of environmental friendliness and energy efficiency is mainly studied by the world's leading countries, including the United States, Canada, Australia, and Western Europe (Belgium, Great Britain, Ireland, Switzerland) and Scandinavia (Finland, Sweden). Challenges related to digital transformation are still being explored in Central and Eastern Europe, but Asian countries such as Taiwan, Bangladesh, and Thailand are still of greater interest (Google Trends, 2024; Telefónica, 2024). This highlights the importance of studying the role of innovation parks in the context of current global trends in digital transformation and energy efficiency, especially given the growing interest in technological innovation in different regions of the world, the need for an integrated approach to creating conditions for the development of innovative processes aimed at optimising resources and reducing energy consumption.

The article aims to study the theoretical basis for the functioning and development of innovation parks in the context of accelerating digital transformation, expanding environmental practices, developing new energy-saving methods and improving modern enterprises' energy efficiency. Thus, the main objectives of the article are:

1) to analyse the current state of development of innovation parks; and, as a result,
2) to identify its key components and efficiency factors;
3) to identify gaps and risks accompanying the process of their functioning in the context of digitalisation and globalisation of markets; and
4) to assess the impact of innovation parks on the development of digital transformation and energy saving in the business sector.

Literature Review

Innovation parks are essential elements of national and regional innovation systems, as they promote innovation and knowledge, support companies, connect them with universities and associations, and facilitate the diffusion of technologies as part of the development of digital transformation (Corrocher, Lamperti and Mavilia, 2019). In this context, Yang, Guangqin and Daqian (2022) note the impact of innovation parks on improving innovation conditions, elements, inputs, and the environment. According to Sandoval-Hamón *et al.* (2024), technology parks are special business zones for mutual work on innovative projects of manufacturing and service companies and the industrial sector. A similar definition is found by Krysovatyy (2024), who describes innovation parks as a platform for cooperation between research institutions, high-tech enterprises, start-ups, and other business entities that stimulate economic growth and scientific and technological progress Sandoval-Hamón *et al.* (2024) through the creation, commercialisation, and integration of the latest ideas into the overall economic system. It should be noted that cooperation of enterprises with innovation parks and members of an industrial or regional cluster is the primary way to effectively implement innovation strategies at the micro level (Mironova *et al.*, 2022). The distinction between the concepts of "innovation park" and "research park" in Pastushenko (2024) shows that innovation parks are structures with solid links between scientific centres (institutes, universities, research centres) and the business sector; and research parks are mainly a derivative structure of research institutions. Earlier studies, in particular Bramwell, Hepburn and Wolfe (2012), Chang *et al.* (2012) and Conicella (2013) note the essence of technology parks as innovation ecosystems aimed at meeting the changing needs of the business sector through the application of the latest knowledge for the development of human capital, financial capital and intellectual property. Campanella, Peruta and del Giudice (2014) understand them as a basis for the efficient use of intellectual assets, particularly human and structural capital. Thus, innovation parks as a catalyst for digital transformation contribute to the development of digital marketing, in particular, online channels for promoting and attracting customers (Goncharenko and Nazarenko, 2022; Niziaieva *et al.*, 2022), development of human resources of enterprises (Kriemadis, 2018), development of mechanisms for state regulation of innovations (Park, Wu and Funk, 2024), improvement of the talent management system and development of corporate social responsibility (González-Masip, Martín-de Castro and Hernández, 2019), environmental efficiency of energy-efficient and green energy technologies, sustainable development of buildings and transition to clean energy (Sotnyk *et al.*, 2023), as well as green (Krysovatyy, 2024) and innovative (Minguillo and Thelwall, 2015) infrastructure, and improved management of

sustainable energy security (Hrinchenko *et al.*, 2024). Kwilinski, Lyulyov and Pimonenko (2024) note that by using digital business practices, including e-commerce sales, online platforms and web applications, companies can optimize their operations, supply chains and implement data-driven energy management strategies; and, consequently, increase resource efficiency and reduce energy consumption in production, distribution and sales processes. Similar findings were reached by Grabowski *et al.* (2024), noting that increasing energy efficiency makes it possible to perform planned actions with less energy consumption. Numerous research findings substantiate the significance of embracing renewable energies in achieving energy efficiency objectives in the post-COVID era (Adao, Narajabad and Temzelides, 2024; Gorina *et al.*, 2024; Panarello and Gatto, 2023). In contrast, Strielkowski *et al.* (2023) highlighted the importance of employing digital tools and technologies in energy networks and smart grids (e.g. Internet of Energy (IoE), peer-to-peer (P2P) prosumer networks, or the AI-powered autonomous power systems (APS) etc.).

Methodology

The study identified crucial components of the efficient growth of contemporary innovation parks through the systematic analysis of literary sources. Thus, the study considered the necessary components for the functioning of innovation parks at the macro, meso and micro levels and included the main influencing factors, in particular innovation policy, government and financial support.

Data sources

The systematization method was utilised to identify the main factors of innovation parks' efficiency and those that hinder their further development. To formulate recommendations, the scientific literature was systematised. The literature was collected through indexing databases such as Web of Science, Scopus and Google Scholar using the following keywords: “innovation parks”, “digital transformation”, “energy efficiency”, and “government support”. The literature search covered the period from 2012 to 2024, which allowed us to cover the preconditions for development and the latest research in this area. By synthesizing various data sources, in particular, case studies and reports of the International Association of Science Parks and Areas of Innovation (IASP), the application of this method provided a consistent structure for identifying recurring patterns and trends.

Analytical framework

The deductive approach was used to theoretically substantiate the relationship between the development of innovation parks and economic progress, to determine the impact of macroeconomic factors on their efficiency, and to determine the impact of macroeconomic factors on the development of innovation parks. The classification method allowed for a systematic division of innovation parks into separate types based on their functions, objectives and industry focus. The application of this method simplified the process of identifying key categories, such as research and development, environmental innovations, digital technologies, etc. To substantiate this classification, information from case studies and regulatory acts of different countries was used. This allowed for the identification of common and unique characteristics of innovation parks, their role in digital transformation, and the assessment of their impact on the socio-

economic development of regions. The use of regulatory acts of different countries provided a more profound understanding of the peculiarities of the functioning of such structures in different conditions, which contributes to the further improvement of approaches to their classification and development.

Expert assessment

To assess the impact of innovation parks on the development of digital transformation and energy saving of modern enterprises, an assessment was conducted based on a survey of experts from technology parks in Ukraine, which is currently experiencing a difficult geopolitical and economic situation. The example of this region will allow us to formulate opportunities, threats and guidelines for business and innovation development in times of crisis. The main objectives of the analysis are:

I. Based on the experts' assessments, determine the importance of innovation parks development efficiency factors (Table 1). In the last stage, the evaluation is carried out, where the value from 0 to 3 points is low efficiency, from 4 to 7 points is medium efficiency, and from 8 to 10 points is high efficiency. The assessment was carried out by participants from the most significant technology parks in Ukraine: Group 1 - residents and employees of LvivTech.City Innovation Park (total = 26 people); Group 2 - residents and employees of UNIT.City Kharkiv Innovation Park (total = 13 people). Calculate the overall level of efficiency of innovation park development in Ukraine.
II. To present the dynamics of critical risks in the activities of innovation parks (Table 2).
III. To conduct a correlation analysis between the performance indicators of innovation parks and the obstacles to their development.

Quantitative analysis

Using the integral method, an integral indicator of the level of efficiency of the development of innovation parks in Ukraine was formed. Based on the data obtained in Excel, the average values for each criterion were calculated, which allowed us to identify the relationship between the effectiveness of innovation parks and obstacles to their development by correlation analysis using the JASP statistical software (Pearson's Correlations tool). The rating assessment of the overall level of efficiency of innovation parks' development was calculated based on six leading indicators: Innovative development (C_I), Infrastructure Support (C_F), Financial support (C_S), Human resources (C_E), Environmental friendliness (C_E), Cooperation and partnership (C_P). The formula for the calculation is as follows:

$$Ef = C_I^2 + C_{In}^2 + C_F^2 + C_S^2 + C_E^2 + C_P^2 \quad (1)$$

Where Ef is the overall level of efficiency of innovation parks development;
C_I – Innovative development;
C_{In} – Infrastructure support;
C_F – Financial support;
C_S – Staffing;
C_E – Environmental friendliness;
C_P – Cooperation and partnership.

Subsequently, an additional assessment of significant hazards associated with the operations of innovation parks was conducted. The results of the expert survey were interpreted according to the following indicators: Regulatory and legal barriers (R1), global competition (R2), the threat of cyber fraud and cyber-attacks (R3), significant cybersecurity costs (R4), industrial espionage risks (R5), imbalance in the development of digital infrastructure (R6), the need for environmental infrastructure (R7), and insufficient motivation to retain scientific and technical specialists (R8).

Generalization and recommendation

The generalization method has been used to formulate promising directions for eliminating the shortcomings of innovation parks in the development of digital technologies and energy efficiency identified during the calculations. For this purpose, a systematic analysis and comparison of existing scientific papers for the period 2012-2024 was carried out, which highlight the problems and opportunities for the development of innovation parks, in the context of digital technologies and energy efficiency. The recommendations concern the regulatory framework, cybersecurity, and strengthening the competitiveness of national innovation parks. To ensure the reliability and accuracy of the results, several methods of analysis were used, including correlation analysis, weighted expert assessments, and comparison with previous studies presented in the relevant scientific literature.

Results

In the current context of globalisation and transformational changes, innovation parks are an essential factor in economic and technological progress, given that they are formed as specialised territories that bring together research institutions, high-tech companies, start-ups and other organisations that contribute to the generation and commercialisation of new knowledge and technologies. In addition, innovation parks perform a crucial function in increasing the competitiveness of regions by stimulating investment, creating new jobs, and intensifying innovation activities (Asheim, 2019). The development of innovation parks is driven by a combination of both internal and external factors, each of which has a significant impact on their efficiency and functioning. Internal factors include, first of all, the availability of a developed infrastructure that provides favourable conditions for research and development. An essential element is also a high concentration of scientific personnel and highly qualified specialists capable of generating new ideas and implementing innovative solutions in various sectors of the economy (Meseguer-Martinez, Popa and Soto-Acosta, 2021). Meanwhile, external factors that determine the macro environment in which innovation parks operate include government support (subsidies, grants, innovation incentive programmes), legal and administrative conditions, global technological trends, and other factors that affect the competitiveness and efficiency of

innovation parks. So, it is essential to identify the main components and conditions to effectively develop modern innovation parks (Figure 2).

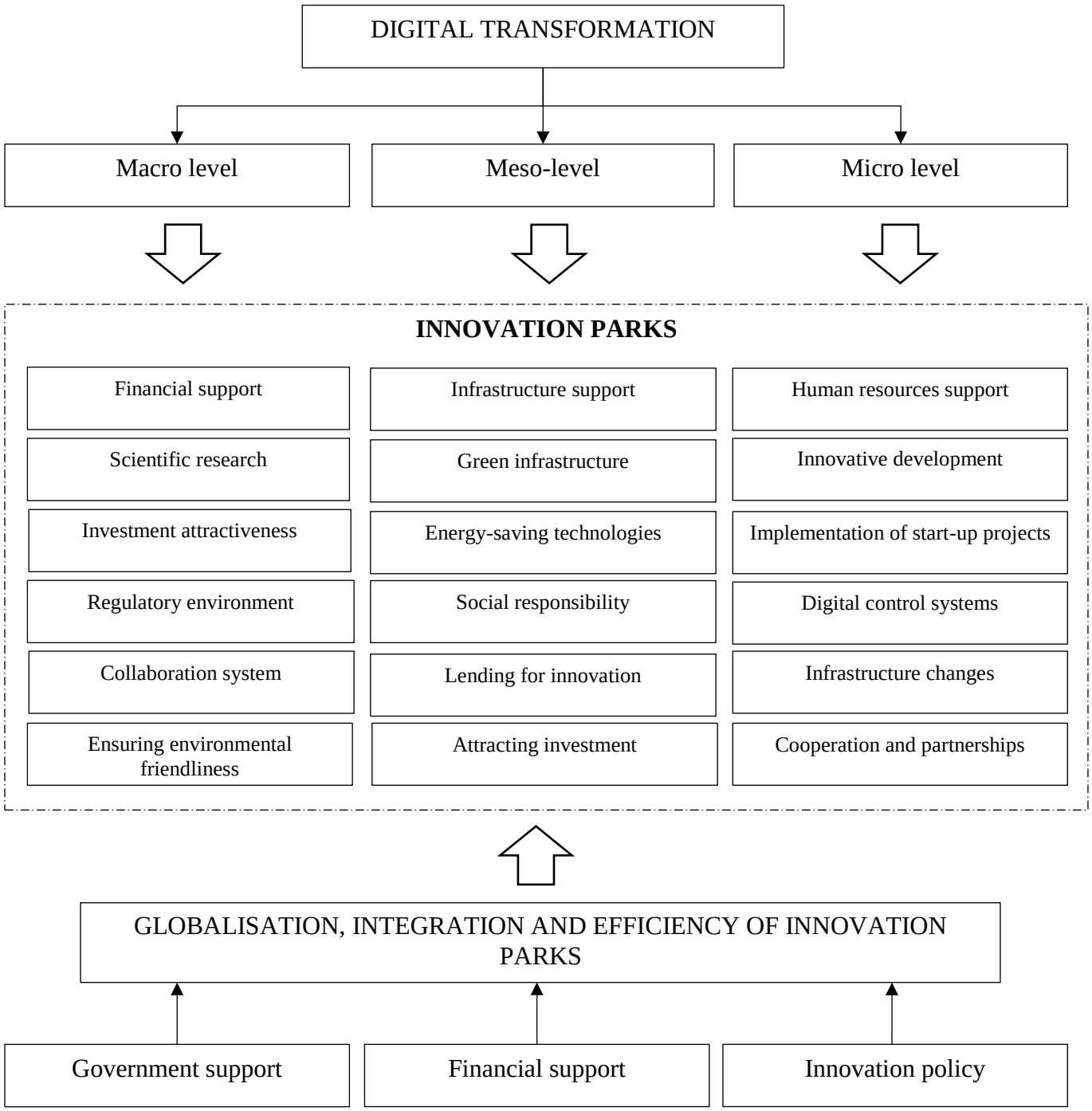

Figure 2: Components of Effective Development of Modern Innovation Parks [*Source:* Kriemadis (2018), Krysovatyy (2024), Mironova *et al.* (2022), Park, Wu and Funk (2024), Pastushenko (2024), Sandoval-Hamón *et al.* (2024), Sanz *et al.* (2023), Yang, Guangqin and Daqian (2022)]

Given the above, the effective development of innovation parks requires a holistic approach combining financial stability, sustainable development principles and technological innovation. An essential prerequisite for the successful development of these structures is active government support, which should include the creation of a flexible regulatory framework, providing financial incentives, and involving the private sector through investment mechanisms. At the same time, research institutions and business entities must actively implement innovative technologies, including environmentally friendly and energy-saving solutions that ensure technological modernisation based on sustainable development. In addition, an essential element is the development of strategic partnerships between science and business aimed at achieving synergies in creating and commercialising innovations.

The current state of development of innovation parks

The development of modern society in the context of digitalisation largely depends on the effectiveness of innovative processes of transforming the content of scientific research and approaches into the latest products, technologies and services (Löfsten and Lindelöf, 2005). The most effective mechanism for implementing this process is innovation formations, particularly science and technology parks, innovation parks, and techno-cities. These are particularly important in implementing innovations and contribute to transferring scientific achievements to the practical sphere (Corrocher, Lamperti and Mavilia, 2019). Such structures ensure the integration of scientific knowledge with industrial needs, creating a favourable environment for the collective work of scientists, entrepreneurs and investors (Atak and Çebi, 2020). In this context, it should be noted that the primary technology sectors in science and technology parks, according to the Global Survey conducted by the IASP in 2022 (Figure 3), are Information and Communication Technologies (ICT), Biotechnology, Software Engineering, Energy, and Artificial Intelligence (AI).

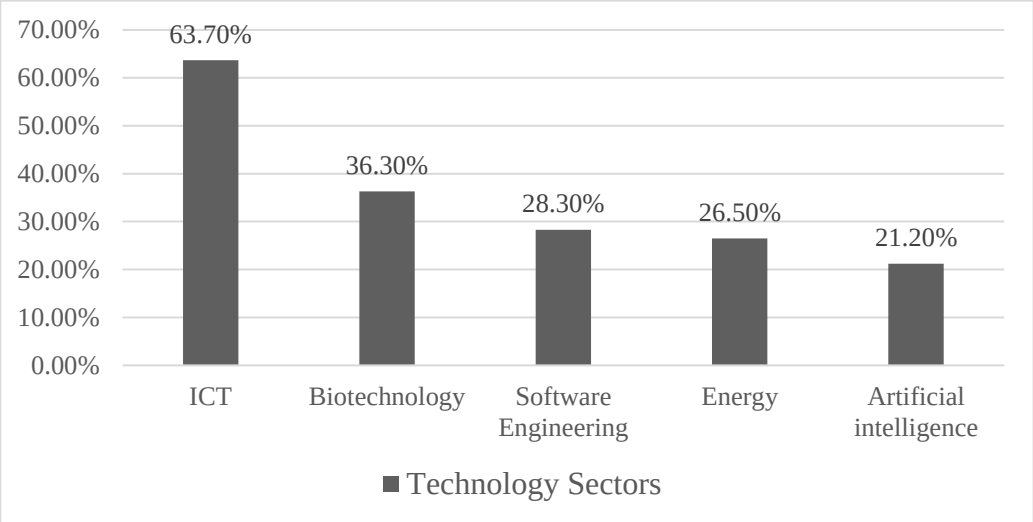

Figure 3: Main Technology Sectors in Science and Technology Parks
Source: IASP (2023)

The largest share within science and technology parks is in the information and communication technology (ICT) sector, namely 63.7%, which indicates the possibility of developing innovation parks by integrating modern technological trends and market requirements. In addition, the biotechnology sector accounts for a significant share (36.3%), which underlines the relevance of innovations in the healthcare and agriculture sectors. It should be noted that the relatively high share of the energy sector (26.5%) is mainly due to the growing interest of the scientific community in energy efficiency and energy saving, in particular, Hrinchenko *et al.* (2024) and Sotnyk *et al.* (2023) point out that innovation parks are an essential tool for implementing sustainable development goals, developing energy efficient and green energy technologies, transition to green energy, waste management, and building green and innovative infrastructure.

Considering the significance of artificial intelligence as a fundamental technology sector in science and technology parks, it is imperative to acknowledge the potential of this direction for resolving energy issues and implementing energy management systems. It is predicted that the global market for energy management systems will reach 52.67 billion USD in 2023, as depicted in figure 1. Such dynamics reflect the growing demand for energy-efficient solutions and technologies that can optimize energy consumption and increase overall energy efficiency.

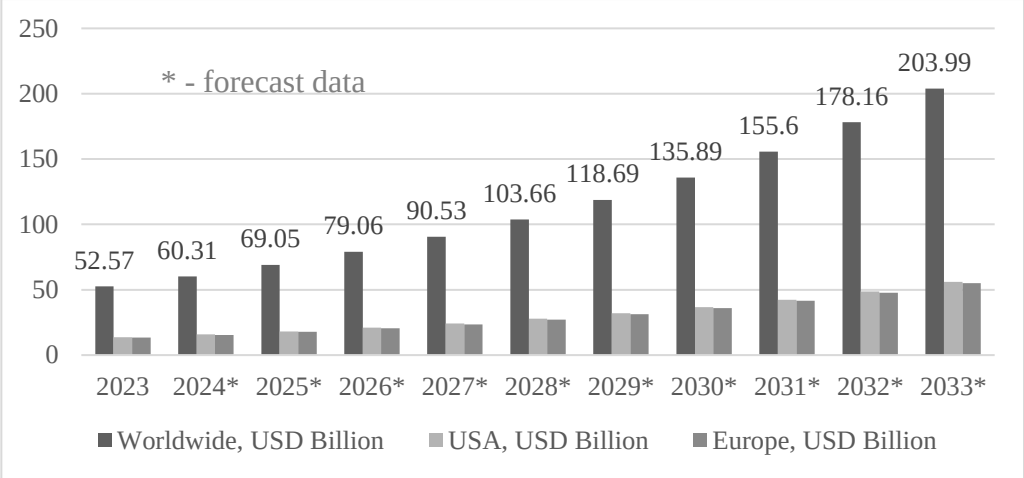

Figure 1: Size and Growth Prospects of the Global Market for Energy Management Systems [*Source:* Precedence Research (2024)]

The current level of development of innovation parks, especially in developed and high-tech countries, is driven by several factors that ensure their efficiency and competitiveness at all levels of operation. According to the Global Survey conducted by the IASP in 2022 (IASP, 2023), Figure 4 shows the main factors that ensure the effectiveness of science and technology parks.

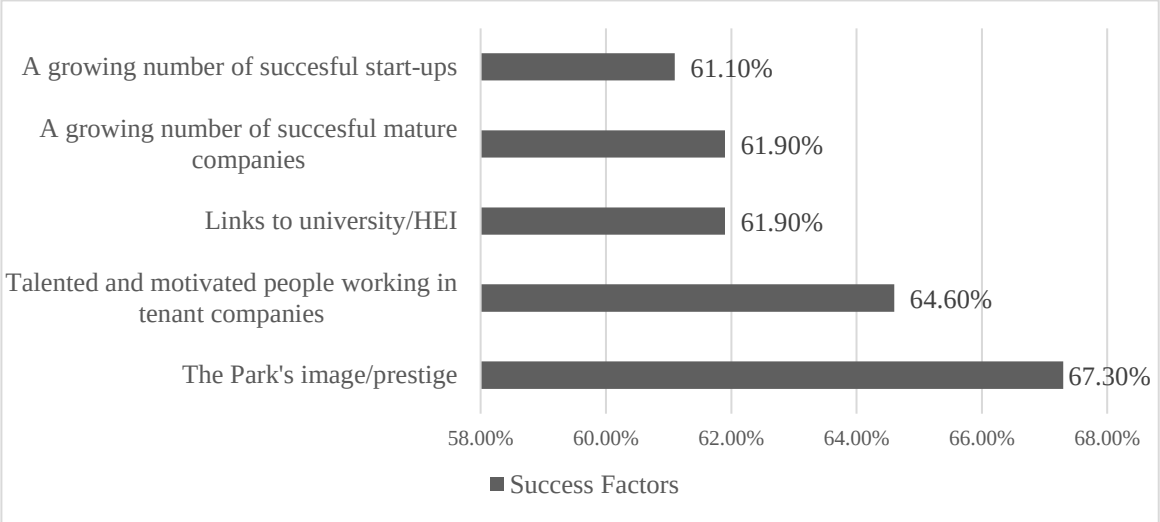

Figure 4: Factors Ensuring the Efficiency of Science and Technology Parks
Source: IASP (2023)

Thus, reputation (67.3%) plays a significant role as an essential element that facilitates the involvement of stakeholders in the development of new solutions and the creation of a favourable innovation environment. At the same time, the quality of human capital (64.6%) is another crucial factor, requiring resident companies to develop relevant approaches to attracting and creating optimal conditions for talented and motivated staff. Ensuring scientific support and access to advanced research for further integration into the work of innovation parks is achieved through the formation of sustainable cooperation and partnership agreements between resident companies and research institutes, universities and higher education institutions (61.9%). However, in addition to the possibility of collaboration with representatives of various scientific institutions and business areas, an innovation park, depending on the level of consideration, may cover global, national, sectoral and local business levels (Kovalko, Eutukhova and Novoseltsev, 2022). That's why it is necessary to consider the distribution of innovation parks by the origin of their resident companies, as determined by the Global Survey conducted by the IASP in 2022 (Figure 5).

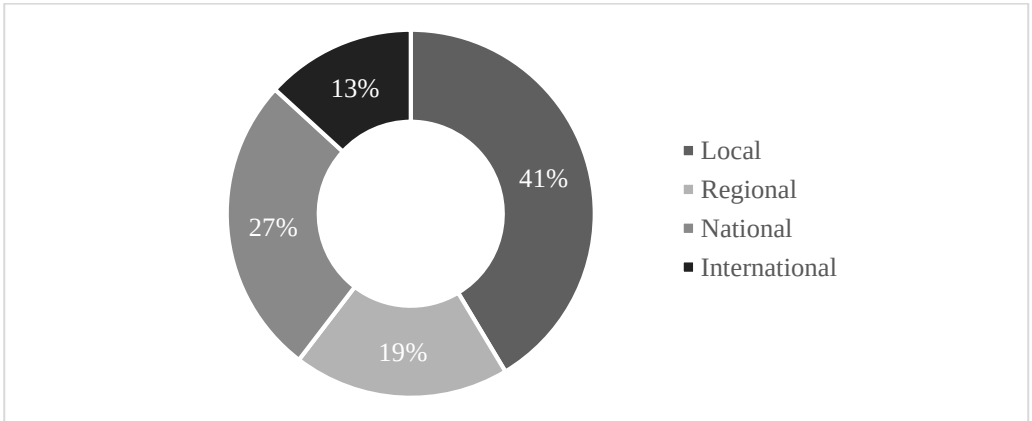

Figure 5. Origin of Resident Companies in Science and Technology Parks [*Source:* IASP (2023)]

Innovation parks are crucial for developing local entrepreneurship (41%) and strengthening innovation activities at the level of regional ecosystems (27%). However, the prospect of increasing the number of national (19%) and international (13%) resident companies is quite positive. However, it requires the development of appropriate measures for cooperation between national-level technology parks to support national innovation initiatives and develop interregional and international partnerships to expand innovation potential and integrate into global markets.

Innovation parks are divided into several types based on their functions, goals, and industries they focus on. These parks are aimed at developing research and development, environmental innovation, digital technology, industry, and the latest developments in agriculture and biotechnology. The classification of innovation parks is shown in figure 6.

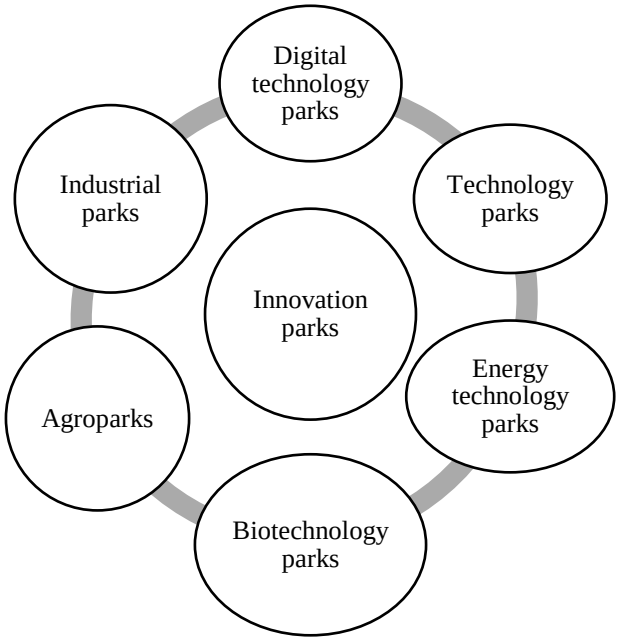

Figure 6: Classification of Innovation Parks [*Source:* Krysovatyy (2024), Mironova *et al.* (2022), Park, Wu and Funk (2024), Sandoval-Hamón *et al.* (2024), Sanz *et al.* (2023), Yang, Guangqin and Daqian (2022]

Technoparks are a significant catalyst for digital transformation, as they integrate the research infrastructure of universities with the industrial sector, creating a synergistic environment for the development of innovative technologies. So, technology parks create an environment that helps companies build relationships with other companies and universities, with the support of structures that keep their companies nearby, which helps to expand knowledge and foster an entrepreneurial and innovative culture. For example, according to the Law on Technology Development Zone No. 4691 of Turkey, a technology development zone is a region where technology or software developed by companies using high and advanced technology or new technologies using the facilities of a particular university or high-tech institute, research centre or institute (Laws of Turkey, 2001); however, there are currently 77 technology development zones in Turkey, and 56 of them are still not operational. In Ukraine, the Law on the Special

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Regime of Innovative Activities of Technology Parks (VRU, 2012) regulates this issue, and the number of innovation parks, although much smaller (16 technology parks), all operate in the market and have some preferential conditions for further development. It should be noted that companies in this region work to transform a technological invention into a commercial product, method or service, thereby contributing to the region's development. In addition, a technology development zone also refers to an area with an academic, economic, and social structure integrated with it within or near the same university, high-tech institute, R&D headquarters, or institute territory. Thus, such technology zones, as confirmed by the findings of Atak and Çebi (2020), provide a comprehensive integration of academic, economic and social potential, significantly enhancing the possibilities of digital transformation. Thus, by increasing the pace of digitalisation, innovation parks can contribute to the green and digital transition, which can help reduce global emissions by more than 15% in sectors such as energy, industry, agriculture, construction or transport, and up to 35% through their ability to change people's habits.

Assessment of the impact of innovation parks on the development of digital transformation and energy saving of modern enterprises

In order to assess the impact of innovation parks on the development of digital transformation and energy saving of modern enterprises, we propose to conduct an assessment based on a survey of technology park experts in Ukraine, which is currently experiencing a difficult geopolitical and economic situation. The example of this region will allow us to formulate opportunities, threats, and guidelines for business development and innovation in the context of the crisis. To conduct a study based on expert assessments, the importance of factors for the effectiveness of innovation parks development was determined (Table 1).

Table 1: Evaluation of Efficiency Factors for Developing Innovation Parks

Criterion	*Areas of evaluation*	*Weighting factor*	*Group 1*	*Group 2*	*Total Group 1*	*Total Group 2*
Innovative development C_I	*1. Innovative development*	*0.25*	*27*	*22*	*6.75*	*5.5*
	1.1. Research and development activities	0.1	10	9	1	0.9
	1.2. Development and implementation of start-up projects	0.08	8	6	0.64	0.48
	1.3. Technological transfers	0.07	9	7	0.63	0.49
Infrastructure support C_{In}	*2. Infrastructure support*	*0.18*	*26*	*24*	*4.68*	*4.32*
	2.1 Digital infrastructure	0.06	9	7	0.54	0.42
	2.2 Transport logistics	0.05	8	8	0.4	0.4
	2.3 Infrastructure for research and development	0.07	9	9	0.63	0.63
Financial support C_F	*3. Financial support*	*0.15*	*27*	*24*	*4.05*	*3.6*
	3.1. Regulatory environment	0.05	8	7	0.4	0.35
	3.2. Financial support instruments	0.05	9	8	0.45	0.4
	3.3 Investment attractiveness	0.05	10	9	0.5	0.45

Criterion	*Areas of evaluation*	*Weighting factor*	*Group 1*	*Group 2*	*Total Group 1*	*Total Group 2*
Staffing C_S	*4. Staffing*	*0.12*	*26*	*26*	*3.12*	*3.12*
	4.1 Social responsibility	0.05	7	9	0.35	0.45
	4.2 Educational programmes	0.04	10	9	0.4	0.36
	4.3. Attracting talent	0.03	9	8	0.27	0.24
Environmental friendliness C_E	*5. Environmental friendliness*	*0.2*	*21*	*29*	*4.2*	*5.8*
	5.1. Green infrastructure	0.07	8	10	0.56	0.7
	5.2. Energy-saving technologies	0.07	7	10	0.49	0.7
	5.3. Waste management	0.06	6	9	0.36	0.54
Cooperation and Partnerships C_P	*6. Cooperation and partnerships*	*0.1*	*22*	*18*	*2.2*	*1.8*
	6.1. System of cooperation	0.04	8	7	0.32	0.28
	6.2. Cooperation with industry	0.03	7	6	0.21	0.18
	6.3. International partnerships	0.03	7	5	0.21	0.15

Based on the results of the analysis of the factors of efficiency of innovation parks' development, experts from LvivTech.City determines that innovation parks achieve the most outstanding results with proper and timely financial support (Total Group 1 = 4.05), as well as in the implementation of innovations (Total Group 1 = 6.75), in particular research activities (1.0), start-up development (0.64) and technology transfers (0.63), which is confirmed by UNIT.City Kharkiv experts (Total Group 2 = 5.5). High consistency between the two groups is also observed in the importance of infrastructure support for the further development of innovation parks (Total Group 1 = 4.68; Total Group 2 = 4.32). Instead, UNIT.City Kharkiv experts consider the development of green infrastructure (0.7) and energy-saving technologies (0.7), and, in addition, the introduction of corporate social responsibility (0.45) to be the most important (Figure 7).

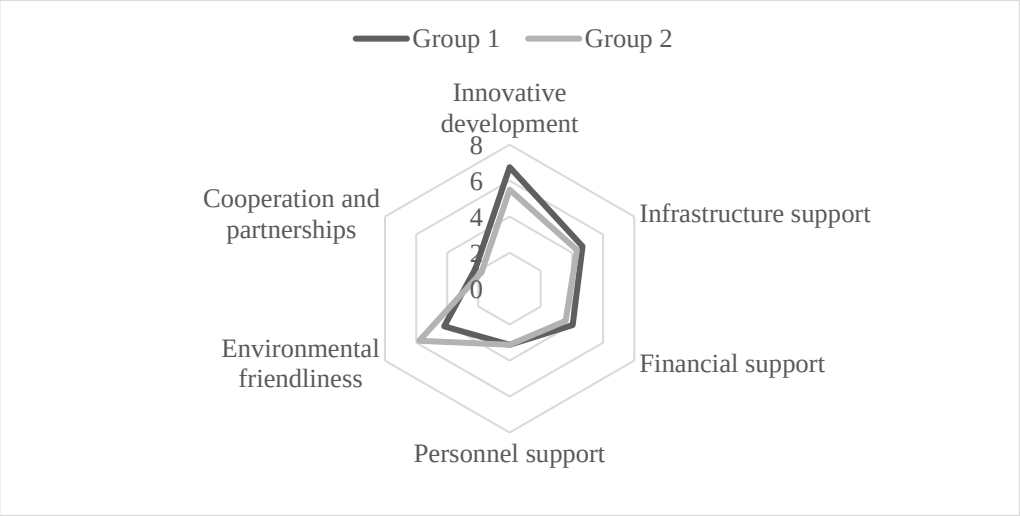

Figure 7: Efficiency Level of Innovation Parks Development

Doi: https://doi.org/10.33002/nr2581.6853.080102 Open Access

The overall efficiency level of innovation parks' development was Ef = 10.77 for Group 1 and Ef = 10.42 for Group 2. This indicates that innovation parks are focused on developing digital and green technologies to increase competitiveness and achieve sustainable development goals in the context of digitalisation and modern economic challenges. The sample of experts formed at the previous stage of the study, which consisted of residents and employees of LvivTech, was used.City (Group 1 = 26 people) and UNIT.City Kharkiv (Group 2 = 13 people), the critical risks in the activities of innovation parks were analysed.

Table 2. Assessment of Key Risks in Innovation Parks' Operations

Criteria	*Weighting factor*	*Group 1*	*Group 2*	*Total Group 1*	*Total Group 2*
Regulatory and legal barriers (R1)	0.15	10	8	1.5	1.2
Competition at the global level (R2)	0.2	9	7	1.8	1.4
Threat of cyber fraud and cyber-attacks (R3)	0.15	9	6	1.35	0.9
Significant cyber security costs (R4)	0.1	8	7	0.8	0.7
Industrial espionage risks (R5)	0.1	5	4	0.5	0.4
Disparity in the development of digital infrastructure (R6)	0.15	7	6	1.05	0.9
Emerging need for environmental infrastructure (R7)	0.1	8	9	0.8	0.9
Insufficient motivation to retain scientific and technical specialists (R8)	0.05	5	7	0.25	0.35

In general, the experts provided high and medium assessments of the critical risks in the activities of innovation parks, namely: LvivTech.City (Group 1) experts found that the most significant challenges are competition (R2 = 1.8), regulatory and legal barriers (R1 = 1.5), which is also noted by the second group of experts, and cybersecurity (R3 = 1.35). Instead, UNIT.City Kharkiv experts (Group 2) argue that uneven development of digital infrastructure (R6 = 0.9) and the need for environmental infrastructure (R7 = 0.9) are the most significant risks for the further development of innovation parks (Figure 8).

A low positive correlation (Pearson's r = 0.240) exists between weighted average estimates of innovation parks' effectiveness and the obstacles to their development. Thus, the existing barriers do not significantly impact the overall efficiency level of innovation parks, and in some cases, their impact is defined as indirect.

Discussion

The study showed that innovation parks, as a catalyst for digital transformation and energy saving, create a platform for the integration of advanced technologies, direct current scientific research, and implement strategies for the introduction of energy-saving technologies and environmental initiatives that ensure their competitiveness and sustainable development. The study revealed that the development of innovation parks in Ukraine is significantly influenced by factors such as innovativeness (Total Group 1 = 6.75, Total Group 2 = 5.5), financial support (Total Group 1 = 4.68, Total Group 2 =

4.32), environmental friendliness (Total Group 1 = 4.2, Total Group 2 = 5.8) and infrastructure (Total Group 1 = 4.05, Total Group 2 = 3.6).

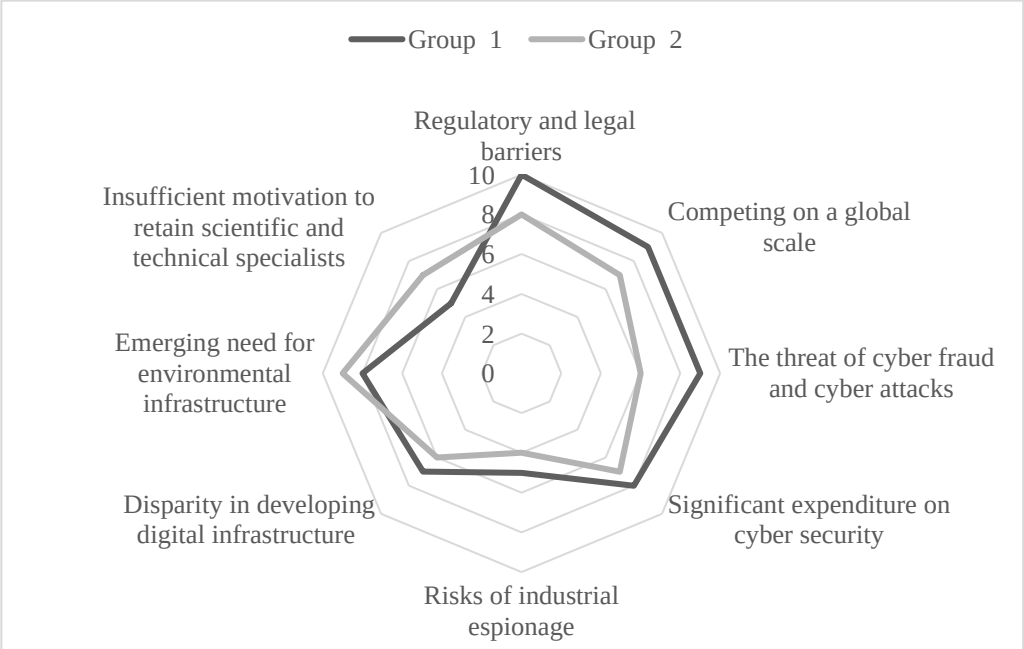

Figure 8: Significance Level of Key Risks in the Activities of Innovation Parks

The study's limitations include a relatively small sample size, focusing solely on Ukrainian innovation parks, and the lack of longitudinal data to assess trends over time. However, the results of the study obtained from the analysis of performance indicators and risks associated with innovation parks conducted by the expert groups should be interpreted with caution due to the small sample size of the expert groups (Group 1 = 26, Group 2 = 13). While these groups provided valuable insights and are sufficient to analyse the characteristics of specific innovation parks, the limited sample size limits the generalisability of the results to a wider population. To generalise the results to innovation parks across the country, it would be necessary to significantly expand the sample size by including in future studies the opinions of experts from more parks representing different regions. Such an approach would ensure broader applicability of the results and provide a more complete understanding of the factors influencing the effectiveness and development of innovation parks at the national level.

The role of innovation parks, according to Kriemadis (2018), is to stimulate key business processes, including innovation management, development of creativity and processes of creating new products and services, as well as to promote cooperation between research institutions and higher education institutions and companies to ensure effective transfer of knowledge, technology and human resources, while supporting joint research and commercialisation of innovative ideas, with the prospect of integrating modern management systems to adapt to the needs of the economy. At the same time, Sandoval Hamón *et al.* (2024), considering science and technology parks as a tool of university policy to promote innovation, believe that their popularity is due to the opportunities for knowledge exchange between universities and industry, thus contributing to the spread

of innovation. Regarding the need to develop innovation parks, mainly based on research institutes and universities, Bramwell, Hepburn and Wolfe (2012) note that universities need to be more aware of developing local industry and related innovation processes in digitalisation. It is worth noting that the main advantage of innovation park development is currently considered to be the ability to ensure the business sector's environmental friendliness and energy efficiency and, in general, sustainable economic development. Studies by Hrinchenko *et al.* (2024), Kovalko, Eutukhova and Novoseltsev (2022), Krysovatyy (2024), Minguillo and Thelwall (2015), Sotnyk *et al.* (2023), Vargas-Hernandez and Vargas-González (2024), Yang, Guangqin and Daqian (2022) confirm the significant contribution of innovation parks to the implementation of sustainable development goals, the development of energy-efficient and green energy technologies, the transition to green energy, waste management, and the development of green and innovative infrastructure. Noting the variability of research findings in modern technology parks' digital technology development, innovation, and environmental friendliness, many relevant scientific papers were analysed.

When implementing innovative technologies, enterprises face several significant barriers, in particular financial constraints. According to Asheim (2019), financial constraints include, firstly, high initial costs of new technologies, as well as further costs of staff training and infrastructure upgrades. In turn, resistance to change is often observed among employees and management due to fear of failure, difficulties in adopting new technologies, and changes in work processes (Löfsten and Lindelöf, 2005). These barriers need to be overcome by adapting corporate culture and supporting innovation in enterprises. It is worth noting the relevance of the work of Kwilinski, Lyulyov and Pimonenko (2024), which emphasizes the importance of integrating digital technologies into the business sector to achieve energy efficiency and promote renewable energy sources. Their findings show that digital business has a positive impact on the implementation of renewable sources, in particular, the share of enterprises with sales through e-commerce has a statistically significant effect on energy efficiency (Et = 0.152), while no significance was found for other variables. Nonetheless, in our investigation, the most significant variable was innovation, specifically research and development activities, which received the highest score among the factors of innovative development (Total Group 1 = 1.0, Total Group 2 = 0.9). However, joining the authors' opinion, we believe that this provides grounds for further development of policies aimed at supporting energy-efficient practices among companies that actively use digital platforms, especially in the context of reducing energy consumption and integrating renewable energy sources into production processes.

In particular, the integrated assessment of indicators for choosing a strategy to stimulate the innovation activities of industrial entities (micro level) in Mironova *et al.* (2022) is an essential methodological basis for representing the level of investment attractiveness of an enterprise in the market. Their findings show that enterprises' innovation potential varies significantly with positive effects. Pastushenko (2024) highlights the need to create a centralised institution for innovation work and improve the institutional structure of innovation management to improve coordination and interaction in forming state support for innovation parks. The effectiveness of the innovation parks development policy, officially, called the National Innovative Polit City Policy (NIPCP), in the context of creating innovative cities was studied by Yang, Guangqin and Daqian

(2022), who found that it is possible to improve the energy efficiency of pilot cities (NIPCP = 0.153) and confirmed the obtained indicators through additional analysis of control variables (NIPCP = 0.162). Krysovatyy (2024) states that the most significant factors influencing the development of innovation parks, according to the results of the weighted expert assessment, are the consideration of innovativeness (WA = 0.92), infrastructure changes (WA = 0.89) and environmental aspects (WA = 0.78), which indicates the need for an integrated approach (a combination of active state policy to support entrepreneurship and education and science with the attraction of financial resources and investment in the entrepreneurial sector). However, deviations are evident in the perception of innovativeness. While Krysovatyy (2024) identified it as the most significant factor (WA = 0.92), our study found financial support (Group 1 = 4.05) and research activities (Group 1 = 1.0) to be more impactful, especially in the Ukrainian context of limited resources and geopolitical challenges. Also, in our study infrastructure support was highly rated by both groups of experts (Total Group 1 = 4.68, Total Group 2 = 4.32), corroborating Krysovatyy's (2024) weighted assessment of infrastructure changes (WA = 0.89). Similarly, environmental friendliness emerged as a critical factor, particularly for Group 2, with energy-saving technologies (Total Group 2 = 0.7) and green infrastructure scoring high (Total Group 2 = 0.7), consistent with Krysovatyy (2024) attribution of environmental aspects (WA = 0.78) as a substantial factor.

At the same time, Corrocher, Lamperti and Mavilia (2019), who conducted a study in Italy among 470 companies located in parks and a corresponding group of 511 companies outside of parks, found that the intensity of innovation depends on the strength of research networks and that science parks have a positive impact on innovation in companies that are already innovative. However, the study conducted in this article shows that the overall level of efficiency of innovation parks development is high (Ef Group 1 = 10.77; Ef Group 2 = 10.42), and the relationship between the efficiency of innovation parks and obstacles to their development, although statistically significant, has a low positive correlation ($r = 0.240$, $p = 0.647$). Thus, the existing risks do not significantly impact the overall efficiency level of innovation parks.

The study has identified several key shortcomings that can be addressed through the following measures.

Strengthen the regulatory framework for innovation parks by integrating more effective management strategies and supporting national and international partnerships, and, as suggested by Park, Wu and Funk (2024), develop mechanisms for government regulation of innovation. In particular, the government should focus on creating a clear regulatory environment to stimulate interaction between innovation parks, academic institutions and the private sector, which will allow for the realization of the potential of digital transformation and energy efficiency. This approach should also be accompanied by an intensification of the commercialization of scientific developments and the upgrading of human resources, which will help accelerate digitalization and the green transition in key sectors of the economy. Meseguer-Martinez, Popa and Soto-Acosta (2021) also note the importance of regulatory obstacles arising from an outdated legal framework that does not always keep pace with rapid technological change.

Develop a multidimensional strategy to ensure the competitiveness of national innovation parks at the global level. Consider the possibility of creating mechanisms for attracting international investment, developing international partnerships and promoting Ukrainian technologies on the global market, based on the example of The National Innovation System of Singapore, which includes a network of international partnerships within the Global Innovation Alliance (GIA), as described in Thukral (2023). In addition, the idea of increasing the competitiveness of regions by stimulating the inflow of investments into innovation parks was also put forward by Asheim (2019).

Reduce the impact of cyber threats on innovation parks by implementing cyber threat monitoring systems, regular software updates, and cybersecurity training for staff. In the context of Ukraine's European integration policy, an available opportunity to strengthen cybersecurity is to join the EU Cybersecurity Strategy programme. In addition, Sozinova, Ilyina and Kusakina (2023) emphasize the critical role of cybersecurity as a foundational element in innovative development and integration forms, such as technology parks and innovative networks. This will allow for the creation of Cyber Threat Monitoring Centres, strengthening cooperation between government agencies and the private sector (Bossong and Wagner, 2018), and developing cybersecurity mechanisms through The European Union Agency for Cybersecurity (ENISA) (Cappelletti and Martino, 2021). However, it is necessary to consider the needs and specifics of national innovation parks, which may require the development of internal mechanisms to prevent cybercrime, especially in the context of Russia's physical and cyberwar against Ukrainian territories and critical systems.

Improve environmental infrastructure by stimulating investment in sustainable development and green technologies to support energy efficiency. Following the example of the Dutch initiative Energiesprong, described in Oostra and Huovinen (2016), we propose to develop a system of government support for energy-efficient technologies for residential buildings, including those operated by innovation parks. In this regard, it is important to consider a public-private partnership mechanism that can be implemented to co-finance projects to convert old buildings into energy-efficient ones using renewable energy sources.

Conclusion

The present study aimed to determine the main aspects of the functioning and development of innovation parks in the context of accelerating digital transformation, expanding environmental practices, developing new energy-saving methods and improving modern enterprises' energy efficiency.

Based on the study's results, it was determined that innovation parks, as a catalyst for digital transformation and energy conservation, primarily provide a platform for integrating advanced technologies and innovative solutions, enabling businesses to optimise operational processes, reduce energy costs, and improve overall efficiency. Secondly, they contribute to implementing scientific research and technological transfers, which, in turn, enhances businesses' innovative potential and competitiveness at both local and global levels. Additionally, they implement strategies for adopting energy-saving technologies and environmental initiatives, aligning with modern state

strategies and sustainable development goals. As a result, they create new business models focused on environmental responsibility and energy efficiency, which are critically important for ensuring economic progress in the face of global challenges.

Future research ought to examine the impact of government policies on the long-term viability and expansion of innovation parks, with a particular emphasis on the interaction between policy incentives and private sector involvement. Furthermore, it would be beneficial to examine the role of innovation parks in fostering international collaboration and their integration into global innovation networks.

This investigation offers vital insights into the growth and efficiency of tech parks, highlighting the crucial elements that contribute to their accomplishment. The findings highlight the importance of government support and infrastructure development for promoting sustainable innovation. Moreover, the findings provide valuable recommendations for policymakers and business leaders aspiring to harness innovation parks as catalysts for digital transformation and energy efficiency in the context of contemporary economic challenges.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	*Author 1*	*Author 2*	*Author 3*	*Author 4*	*Author 5*
Conceived and designed the research or analysis	Yes	No	Yes	Yes	Yes
Collected the data	Yes	No	Yes	No	No
Contributed to data analysis & interpretation	Yes	Yes	No	Yes	No
Wrote the article/paper	Yes	Yes	Yes	Yes	Yes
Critical revision of the article/paper	Yes	Yes	Yes	Yes	Yes
Editing of the article/paper	Yes	Yes	Yes	Yes	Yes
Supervision	No	Yes	No	Yes	Yes
Project Administration	Yes	No	No	No	No
Funding Acquisition	No	No	No	No	No
Overall Contribution Proportion (%)	20	20	20	20	20

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Research involving human bodies or organs or tissues (Helsinki Declaration)
The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

Research involving animals (ARRIVE Checklist)
The author(s) solemnly declare(s) that this research has not involved any animal subject (body or organs) for experimentation. The research was not based on laboratory experiment involving any kind animal. The contexts of animals were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of ARRIVE does not apply in cases of this study or written work.

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Research involving Plants
The author(s) solemnly declare(s) that this research has not involved the plants for experiment and field studies. Some contexts of plants are also indirectly covered through literature review. Thus, during this research the author(s) obeyed the principles of the Convention on Biological Diversity and the Convention on the Trade in Endangered Species of Wild Fauna and Flora.

Research Involving Local Community Participants (Non-Indigenous) or Children
The author(s) solemnly declare(s) that this research has not directly involved any local community participants or respondents belonging to non-Indigenous peoples. Neither this study involved any child in any form directly. The contexts of different humans, people, populations, men/women/children and ethnic people were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or prior informed consent (PIC) of the respondents or Self-Declaration in this regard does not apply in cases of this study or written work.

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)
The author(s) has/have NOT complied with PRISMA standards. It is not relevant in case of this study or written work.

Competing Interests/Conflict of Interest
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